3.E.1.e   (3) (cont'd) should be applied to the cathode, not the anode. This is because any imperfection in the paint, if applied to the anode, would result in an even more unfavorable cathode/anode area ratio. For the same reason, care should be exercised when applying noble metal coatings on a less noble base metal (e.g. chrome plate on carbon steel). If the coating contains any imperfection, the large cathode to anode area ratio can cause severe corrosion of the base metal in the localized region of the imperfection.

(4) Pitting Corrosion. This form of galvanic corrosion occurs as the result of local cells that develop on the surface of a single material. These cells arise from local environmental differences. Aluminum alloys with heavy metal alloying elements, such as copper, nickel, and iron, are subject to severe pitting. This results from the anodic behavior of the aluminum matrix and the cathodic behavior of the heavy metal alloying elements. Metals that form a protective oxide film, such as the stainless steels, are highly susceptible to pitting. These, more so than carbon steels, pit greatly because any local breakdown of the film exposes a local active area of less noble character.

(5) Intergranular and Selective Phase Corrosion. This type of corrosion is due to heterogeneities in the metal that result in preferential corrosion of one of the components of the alloy. Several examples of this type are:

(a) Intergranular corrosion of austenitic stainless steels as the result of carbide precipitation at the grain boundaries;
(b) Dezincification of brass and bronze containing more than 15 percent zinc; and
(c) Dealuminization of some aluminum bronzes in which the aluminum-rich gamma phase is selectively attacked.

(6) Stress Corrosion. Stress corrosion is a form of local deterioration resulting from the combined action of static stress and corrosion, which leads to cracking of alloys. This corrosion only occurs in the presence of tensile stresses, which may be applied and/or residual. Stress corrosion of a particular material usually occurs only in specific environments, which may be only mildly corrosive in the absence of stress. Steels produced to a yield strength in excess of 150,000 psig are susceptible to stress corrosion in a marine environment. Many aluminum alloys in the 2000 to 7000 series are susceptible to stress corrosion in seawater.

f. Use Of Stainless Steel Materials.

(1) Introduction. Stainless steels develop a thin oxide layer that protects the metal from surface corrosion. The development of this protective film is known as passivating. Some authors define chromium-nickel steel as "stainless" if it contains as little as 10 percent chrome; others regard 11.5 percent chrome as the minimum possible amount for passivating to occur. Chlorides dissolve this passivating film. However, if ample oxygen is available, the oxide film restores itself as fast as it is broken down, and the surface remains protected. At any location where

3.E.1.f (1) (cont'd) oxygen is kept out, deep pitting may occur because the chlorides destroy the passive film and the spot becomes active. Active and passive spots on the same piece of stainless steel can be so galvanically different as to cause rapid deep pitting. Once a pit starts, it serves as an active spot where the chloride reaction products themselves keep the oxygen out and corrosion can continue. Stainless steel parts in stagnant saline water, located in such places as low points in piping where water accumulates or fuel tanks in bilges of small boats, may be subject to this type of concentrated and rapid pitting attack. Even when the surfaces are exposed to ample oxygen, crevices may become stagnant or fouled areas and, therefore, active pits may develop. Susceptibility to chloride action can be greatly reduced (although not totally eliminated) in several ways:

    (a) By increasing the chromium content to 25 percent and the nickel content to 20 percent, rather than the common 18 percent and 8 percent mixes;

    (b) By the addition of 2-3 percent molybdenum (316 and 316L);

    (c) By decreasing the carbon content (304, 304L, 316L);

    (d) By selecting chromium and nickel equivalents to keep more austenite and less ferrite in the metal. For equivalents and percentage of ferrites, see the Schaeffler diagram, Figure 65.5, of the AWS Welding Handbook, Volume 4 (6th ed.). However, some of the desirable corrosion-resisting additives also promote ferrite formation; or

    (e) By avoiding sulfur and selenium, which are sometimes added to enhance free-machining properties.

(2) Extra-Chloride Corrosive Effects. In addition to pitting at any random point in the material as described above, pitting in the grain boundaries, intergranular corrosion, and stress corrosion cracking can occur. The same chloride attack is contributory, but these types of corrosion occur in the grain boundaries due to a depletion of chrome or a buildup of carbon, thus negating the benefits indicated in items (2) and (3) above. This effect can be reduced by:

    (a) Not allowing the material to remain any longer than necessary at temperatures between 350 and 927°C (662-1700°F), or, if this has already occurred, by heat treating the material above 1010°C (1850°F) and quickly cooling. (See UHA-100 through 108 of Section VIII, Division 1 of the ASME Code.)

    (b) Avoiding the edges of as-rolled plate. Rolling orients the grains in such a way that those grain boundaries perpendicular to the edge corrode more rapidly. Pit nuclei, therefore, exist at the edges of sheets, and fresh-cut edges are less likely to have active pits already started.

    (c) Avoiding cold-working and hot-working. Such areas are likely to have intergranular problems somewhere within or adjacent

3.E.1.f(2)   (c) (cont'd) to the affected area, unless the cold or hot-working is followed by heat treating as in (1) above.

                (d) Adding titanium or columbium. For this purpose, there should be four to six times as much titanium, or eight to ten times as much columbium, as carbon. In welding electrodes, columbium is preferable to titanium.

       (3) <u>Consideration In The Use Of Stainless Steels</u>.

          (a) <u>Introduction</u>. From the above discussion, it is clear that stainless steel is not always "stainless" and should not always be considered a suitable substitute for carbon steel. For this reason, the reader is cautioned that the term "steel," when used in the regulations, may not include "stainless steel." For example, 46 CFR Table 58.50-5 lists "steel" as an acceptable material for independent fuel tanks. However, Note 4 requires that the "steel" be galvanized. Thus, "stainless steel" is not included in the general term "steel," and its use must be specifically approved. Although one specific material such as properly heat treated 316L is likely to be clearly best, the Coast Guard often must decide whether something less than the best is acceptable or unacceptable in a particular application.

          (b) <u>Certification by a Metallurgist</u>. Engineers will differ as to where to draw the line between acceptable and unacceptable. If a material manufacturer's metallurgist, who is familiar with marine applications, certifies that the proposed material, design, welding, heat treatment and other pertinent details are an acceptable combination in the proposed location and service, this will generally be acceptable. A greater degree of documentation or testing may be required in new applications in vital or hazardous services. A lesser degree of information will often be acceptable in many routine applications.

          (c) <u>Restrictions in "Freshwater" Service</u>. The pitting problem should not be disregarded for non—ocean service. Chloride ions exist in sufficient quantity to pit some stainless steels in many waters normally regarded as "fresh." Natural minerals, road salt runoff, industrial and agricultural pollutants, and brackish water in estuaries can all contribute chlorides in sufficient quantities to cause active pitting in the absence of ample oxygen for passivating. Also, evaporation will increase the chloride concentrations in bilges, crevices, and similar locations. Stainless steels should, therefore, generally not be accepted in stagnant water services, such as boat tanks located in bilges and other wet, unventilated areas. In dry, well-ventilated areas (such as the upper levels of engine rooms), the better marine alloys may be used without coatings and with reasonable control of crevices and cleanliness.

          (d) <u>Restrictions In Deck Equipment</u>. On deck, the better marine alloys may be used without coatings, but with every effort to minimize crevices. Inspectors should be aware that such

3.E.1.f(3)   (d) (cont'd) items as LNG piping (which is generally made from such materials as 304L stainless steel, for other reasons) should be carefully examined for crevice corrosion around gaskets, at the edges of insulation where imperfect sealing may allow salt to collect, etc. [NOTE: Listing of an alloy in 46 CFR 56.50-105 as "acceptable for cryogenic piping" does not imply that it is acceptable in all locations aboard ship.]

(e) Restrictions Against Coatings. Coatings, which have been accepted for stainless steel boat fuel tanks under a previous policy, are a less desirable solution. Slight damage to coatings, such as peeling, cracking, etc., can concentrate pitting at the point of damage. Coatings may hide perforations of the metal due to internal pitting, which may occur when saline water gets into fuel tanks, until fire damage to the coating reveals that the supposedly fire-resistant stainless steel has been holed. In most cases, the use of stainless steels should be accepted without coating or prohibited. Only in special cases, as when a boat with existing stainless fuel tanks comes into inspected service, should acceptance of a coating be considered; acceptance in such cases should be limited to tanks that can be readily inspected inside and out.

(f) Use In Vessel Tanks. Because chloride pitting can completely hole a thin tank between required Coast Guard inspections, stainless steel tanks should be required to be no thinner than carbon steel tanks, in accordance with the tables in 46 CFR 58.50, and 182.440(A)(1), if permitted at all.

(g) Summary. All of the information above concerns normal and low temperature service. Chloride pitting becomes more severe very rapidly at high temperatures. In some alloys, this transition may occur at as low as 125°F. Different alloys may be better for hot, fast-flowing saltwater service such as cooling water discharges. Such special applications must be considered individually. The sources cited below do not show any actual data for corrosion at cryogenic temperatures, but the corrosion rate curves available seem quite flat throughout the ambient temperature ranges. Therefore, corrosion is likely to be the same or lower at very low temperatures, and should be evaluated at ambient temperatures unless data showing a significant reduction is submitted.

(4) Additional Information. Further information may be obtained through the following sources:

(a) Marine Corrosion: Causes And Prevention, Francis L. LaQue; Wiley, New York, 1975.

(b) The Corrosion Handbook, H.H. Uhlig, Ed.; Wiley, New York, 1948.

(c) Corrosion (2nd Ed.), Volumes 1 and 2, L. Shreir, Ed.; Newnes— Butterworths, London, 1976.